# Analysis and High Resolution Modeling of Tropical Cyclogenesis During the TCS-08 and TPARC Field Campaign

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## LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved understanding of the fundamental mechanisms involved. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC genesis and intensity is the lack of observations prior to and during TC genesis and intensification periods and the inadequate understanding of physical mechanisms that control the cyclogenesis and intensity change. The TCS-08 and TPARC field campaign provide an unprecedented opportunity for us to gain the first-hand insight of observed characteristics of TC genesis in western Pacific and to compare them with high-resolution model simulations. By analyzing and assimilating these data, we intend to understand the physical mechanisms that involve the TC internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after thoroughly understanding these processes, can one be able to tackle the weaknesses in the current state-of-art weather forecast models.

## OBJECTIVES

The objective of this project is to conduct a thorough investigation on what initial precursor conditions (e.g., thermodynamic variables such as moisture and temperature vs. dynamic variables such as wind) are most critical for TC genesis, taking advantage of 2008 TCS-08 and TPARC observational products. We plan to produce a 3D high-resolution reanalysis product for the western North Pacific (WNP) during the intense observational campaign period, and to conduct high-resolution model (such as COAMPS or WRF) cyclogenesis forecast experiments with use of the data assimilation products as

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14. ABSTRACT
**The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved understanding of the fundamental mechanisms involved. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC genesis and intensity is the lack of observations prior to and during TC genesis and intensification periods and the inadequate understanding of physical mechanisms that control the cyclogenesis and intensity change. The TCS-08 and TPARC field campaign provide an unprecedented opportunity for us to gain the first-hand insight of observed characteristics of TC genesis in western Pacific and to compare them with high-resolution model simulations. By analyzing and assimilating these data, we intend to understand the physical mechanisms that involve the TC internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after thoroughly understanding these processes, can one be able to tackle the weaknesses in the current state-of-art weather forecast models.**

15. SUBJECT TERMS

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initial conditions. We will examine how the cyclogenesis forecast may be significantly improved with better descriptions of the dynamic and thermodynamic precursor signals.

**APPROACH**

We plan to conduct the following two major tasks: 1) high-resolution TC genesis forecast and simulations to understand cyclogenesis mechanisms, and 2) typhoon reanalysis during the TCS-08 and TPARC campaign period to reveal 3D moisture and temperature structure and evolution characteristics during the TC genesis period.

For the first task, we will conduct high-resolution modeling to understand physical process associated with TC formation and identify key atmosphere variables for accurate prediction of tropical cyclogenesis. By diagnosing the model outputs, we will address science questions related to the observed moisture discharge and recharge and rainfall oscillation prior to TC genesis and fundamental difference between the “bottom up” and the “top down” genesis scenarios.

For the second task, because the TCS-08 and TPARC campaign provides variety types of in-situ data at irregular spatial and temporal intervals, we intend to construct a high-resolution regular-grid reanalysis product that combines all types of (field and remote-sensing) observations together. The data assimilation system to be used is either NRL Atmospheric Variational Data Assimilation System (NAVDAS) or WRF 3DVar system. We are currently collaborating with NRL-MRY scientists (Dr. Nancy Baker) in implementing the direct satellite radiance assimilation technique into the COAMPS. The reanalysis will cover the entire TCS-08 and TPARC campaign period, with a horizontal resolution of 5-10 km and a time interval of 1-3 hours. Our assimilation strategy is to combine the in-situ observations (such as ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) with multi satellite products.

**WORK COMPLETED**

In the high-resolution modeling aspect, both real-case and idealized simulations of TC genesis in the western North Pacific are conducted. A real-case simulation of Typhoon Prapiroon (2000) associated with the Rossby wave energy dispersion of a pre-existing TC has been analyzed in great details, and a paper is accepted and will appear in 2009 Monthly Weather Review. Different from this typical “bottom-up” genesis scenario, another genesis type associated with a “top-down” development is also successfully simulated in a cloud-resolving model. A detailed analysis of the model output is currently being carried out, and a manuscript is in preparation.

Meanwhile, we collected the 2008 in-situ observational campaign data products (e.g., ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) and multi satellite products, and assimilated these data into the WRF 3Dvar assimilation system.

**RESULTS**

By using a high-resolution cloud resolving model (WRF-ARW), TC genesis from an initial mid-level mesoscale vortex with a “cold core” structure is successfully simulated. The objective of this study is to understand the “top-down” genesis scenario in a quiescent environment. The numerical results suggest that a crucial condition for TC genesis is to establish a near-saturated air column in the genesis region. The vortex development experiences multiple convective-stratiform cloud phase transitions towards reaching such a near-saturated air column (Fig. 1). The initial neutral stratification becomes convectively unstable due to near-surface moist static energy accumulation. This stimulates strong convective activity characterized by “vertical hot towers”. With the enhanced latent heating released by the convective bursts, the lower level cold-pool becomes less distinct with time. As the convective bursts decay, a stratiform cloud stage appears, and is characterized by an enhancement of the mid-level vorticity maximum and the “cold core” (at 48~60h). Thereafter, the “cold-core” structure collapses rapidly as the sea level pressure drops dramatically. A TC with a significant “warm-core” structure is established at t=72 hr.

The transition above is followed by another eruption of strong convective activity. In the stratiform cloud region, the mid-level dryness and cooling associated with mesoscale downdrafts are responsible for a mid-level minimum of $\theta_e$. This reduction along with the recharge of PBL moisture due to surface evaporation leads to the re-establishment of a convectively unstable stratification, and thus brings about a new convective episode. The result above points out that the stratiform cloud may act as a pace maker to destabilize the atmosphere and trigger new convection. Through the oscillation process, the atmospheric moist layer deepens, which is crucial in preconditioning the environment for the TC development.

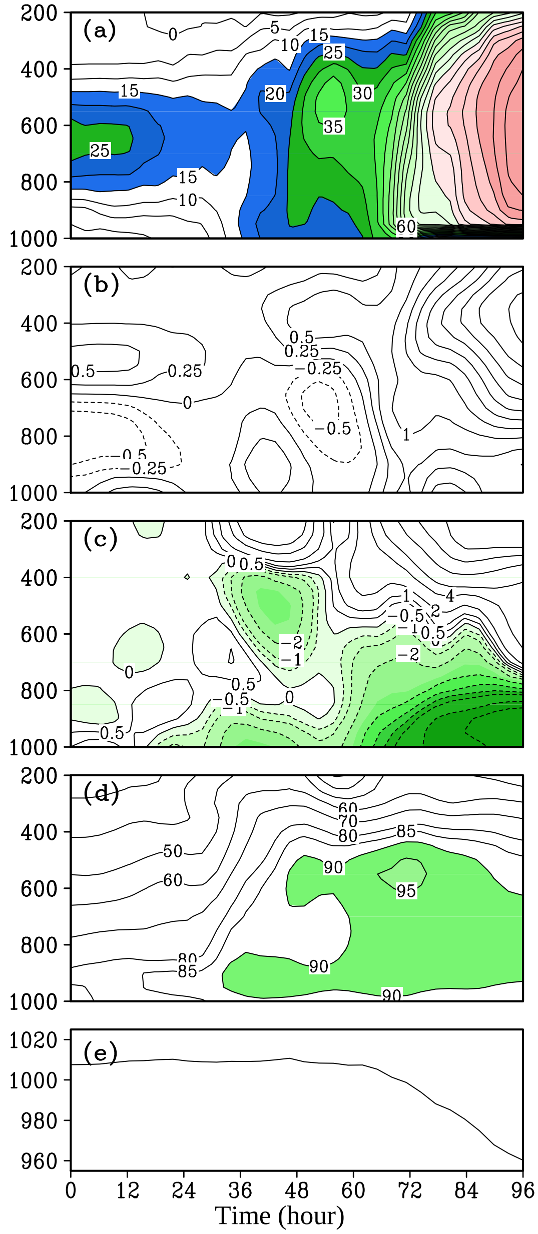


***Fig. 1 The time-vertical pressure level cross section of mean values of inner-core variables averaged over an area of 100km×100km box center at the MSLP: (a) relative vorticity (×$10^{-5}$ $s^{-1}$); (b) temperature anomaly (℃); (c) divergence (×$10^{-5}$ $s^{-1}$); (d) RH (%); (e) MSLP (hPa).***

By partitioning the convective and stratiform regions, we elucidated that the convective regions are responsible for the generation of the lower-level cyclonic vorticity, and the stratiform regions account for the mid-level cyclonic PV generation (Fig. 2). In the convective (stratiform) region, the vorticity is maximized in the low- (mid-) level, which is ascribed to the horizontal divergence fields (Fig. 2 c-d). The divergence evolution shows significant differences between the convective and stratiform regions. The vertical wind profiles clearly show low-level convergence and upper-level divergence structures in convective regions and the midlevel convergence sandwiched between lower- and upper-level divergences in stratiform regions. Given that the convergence areas correspond to the cyclonic vorticity maximums, it implies that the relative vorticity is primarily due to the stretching effect. In the course of the vortex development, the convection precipitation plays a dominant role in the cyclonic vorticity generation; and the stratiform precipitation become increasingly important after the convection ceases. The convective cells play dominant roles in the changes of the vortex dynamic and thermodynamic fields. Consistent with Montgomery et al. (2006), the vorticity is derived from the convective cells that contain a “bottom-up” process, which is in contrast to the “top-down” scenario in which the surface vorticity is ascribed to the downward advection of the mid-level vorticity perturbation.

A sensitivity experiment with different initial settings also simulates the same enhancement of the mid-level vortex prior to the TC genesis and similar convective -stratiform cloud phase transitions. Therefore, the “bottom-up” and “top-down” scenarios co-exist in real cyclogenesis cases, reflecting different development phases.

## IMPACT/APPLICATIONS

The understanding of the cyclogenesis mechanisms and the improvement of NAVDAS data assimilation are critical to improve the NOGAPS and COAMPS predictions of TC genesis and TC intensity change.

## TRANSITIONS

Results from this study may lead to improvements in the NOGAPS and COAMPS prediction of tropical cyclone genesis and intensity change. The data assimilation strategy for TC initialization may transition into a 6.4 project.

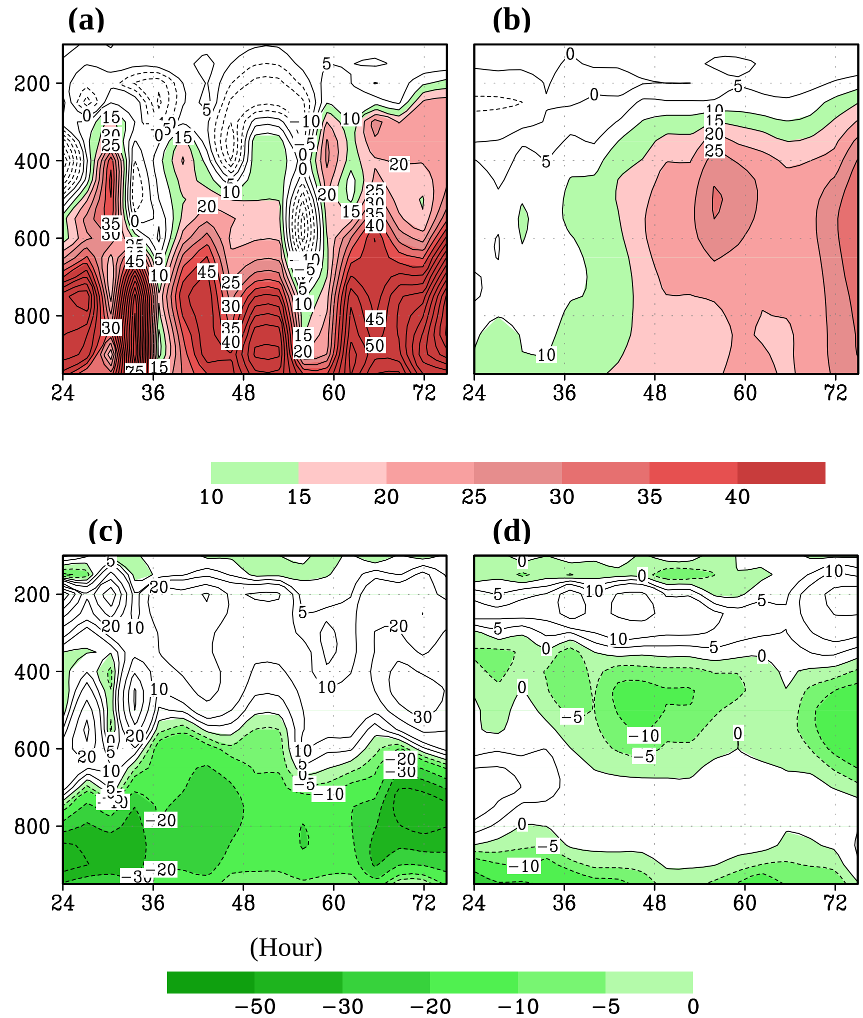


***Fig. 2 Time-vertical cross section during t=24-72 hr of mean relative vorticity in (a) convective regions within inner 100 km; (b) as in (a) but for stratiform region; (c) as in (a) but for horizontal divergence; (d) as in (c) except for stratiform regions. Units: $1\times10^{-5}$ $s^{-1}$.***

## RELATED PROJECTS

This project is closely related to the ONR funding entitled "Western Pacific tropical cyclone reanalysis with the NRL Atmospheric Variational Data Assimilation System (NAVDAS)" in which we conduct the typhoon reanalysis for 2005-2007. Knowledge gained from this project will help assimilate TCS-08 and TPARC observational data and improve the model initial condition for TC prediction.

## PUBLICATIONS

In the following we list the publications that are fully or partially supported by this ONR grant:

Ge, X., T. Li, and M. S. Peng, 2009: Cyclogenesis simulations of Typhoon Prapiroon (2000) associated with Rossby wave energy dispersion. Mon.Wea.Rev, in press.

Peng , J., T. Li, M. Peng, and X. Ge, 2009: Barotropic instability in the tropical cyclone outer region. Quart. J. Roy. Meteor. Soc., 135, 851-864.

Peng, J., T. Li, and M. Peng, 2009: Formation of tropical cyclone concentric eyewalls by wave-mean flow interactions. *Advances in Geosciences*, Vol. 10, ISBN: 978-981-283-611-3.

Li, T., 2009: Monsoon climate variabilities. *AGU Book Chapter, Editor: D.-Z. Sun*, in press.

Wen, M., T. Li, R. Zhang, and Y. Qi, 2009: Structure and Origin of the Quasi-biweekly Oscillation over the tropical Indian Ocean in Boreal Spring. *Journal of the Atmospheric Sciences,* in press.

Li, Chunhui, T. Li, et al., 2009: Interdecadal Variations of Meridional Winds in the South China Sea and Their Relationship with Summer Climate in China. *Journal of Climate,* in press.

Li, T., and C. Zhou, 2009: Planetary Scale Selection of the Madden-Julian Oscillation. *J.Atmos.Sci*., 66, 2429-2443.

Hong, C.-C. and T. Li, 2009: The Extreme Cold Anomaly over Southeast Asia in February 2008: Roles of ISO and ENSO, *J. Climate*, IPRC-580, 22,3786-3801.

**Manuscript in preparation**

Ge, X., T. Li, and M. S. Peng, 2009: Cloud-resolving model simulations of an idealized top-down cyclogenesis event.